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Static analysis of 6KW 45V PEM fuel cell stack with respect to pressure of reactants and operating temperature

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***Abstract*— Fuel cell stacks are considered to be a vital competitor in renewable energy systems. The clean process involved in electricity generation, renewable, silent operation, portability, weather independence and instance of operation gives them the leverage over other sources of energy. The output obtained from a fuel cell is low thus a fuel cell stack is used in many cases. The performance of the fuel cell stack depends on the number of cells used, flow rate of the reactants employed, pressure of the reactants employed, operating temperature, reactant composition etc. In this paper the performance of a 6 kw 45 V PEM fuel cell stack is analyzed using simulations with respect to various pressure of reactants and operating temperatures. The simulation is backed with the mathematical equations.**

***Index Terms*—Fuel cell stack, Renewable energy, Static analysis, Performance analysis.**

I. INTRODUCTION

In present scenario energy requirements are booming and unconventional means of energy production are getting more exposure than the past. One of the greatest techniques available today for electrical energy generation is fuel cell. They directly convert fuels in to electricity by electrochemical process rather than transitions to different forms consequently the efficiency of them are relatively high. Moreover these fuel cells are flexible and doesn't produce any noise during their operation. They can continuously operate provided the fuel is fed. The emissions from these units are also almost nil. Thus making them environmentally friendly. However the energy obtained for a single fuel cell is rather small i.e. in the range of 1 to 1.5 volts. Thus practically a series of cells are connected together and a stack.

The number of cells employed in a stack determines the output voltage, current and the arrangement of cells determine the temperature of the stack. For a particular fuel cell stack the amount of fuel and oxidant consumed is determined by the number of cells employed, the power rating of the stack, the efficiency of the stack and the composition of fuel and oxidant employed.

In addition to the previously mentioned parameters the amount of reactants also depend on the pressure with which the fuel and oxidants are fed and also on the operating temperature of the stack. Thus in designing a fuel cell stack proper stress should also be given to the pressure of the stack and operating temperature of the stack. Owing to the additional cost that may be incurred in the implementation these three parameters are having very narrow zone for design. In the same scenario when properly designed with the pressure and temperature of the stack in to consideration a greater amount of fuel and oxidant can be saved . This paper is aimed at discussing the effect of pressure and temperature on the performance of the stack and it concludes with the best value of pressure of reactants.

II. FUEL CELL

Electrical energy, water and heat are generated in a fuel cell when fuel and air reacts through a porous membrane called as electrolyte, which separates them. The reaction results in electron transfer and thus a potential creation when an external load is connected with the device.

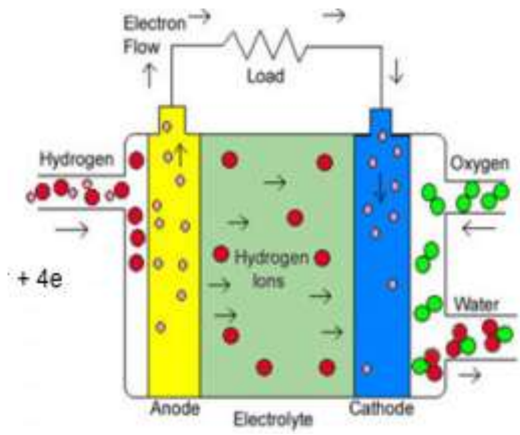

Fig. 1. Fuel Cell

The overall chemical change that occurs within the fuel cell stack can be given by the following equation.

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$$2H_2 + O_2 \longrightarrow 2H_2O + energy$$

The fuel for the stack is fed at the anode while the oxidant is fed at the cathode. Within the stack both oxidation and reduction occurs thus called as the redox reaction. At the anode hydrogen loses electrons on reaching the PEM which doesn't allow electrons to pass through thus leaving hydrogen ion and electron, the hydrogen ion passes through the electrolyte while the electro n passes through the external load. The hydrogen ion on reaching cathode combines with the oxygen and electrons to form water. The anode half reaction and cathode half reactions are given below.

$$\text{Anode Half - Reaction } 2H_2 \longrightarrow 4H^+ + 4e^-$$
$$\text{Cathode Half - Reaction } O_2 + 4H^+ + 4e^- \longrightarrow 2H_2O$$

III. Performance Parameters

The output voltage, output current, fuel consumed, oxidant consumed, efficiency are all the important performance parameters to be considered. The output voltage obtained from the stack as from the equation (1) is dependent on the Nernst voltage of the individual cell and the stack constant.

$$E_{oc} = K_c E_n \qquad (1)$$

The utilization of fuel and oxidant depends on many a factors such as the operating temperature, number of cells employed, current generated from a single cell, pressure of the reactants, volume of reactants involved and the percentage of reactants in the reacting mixture. The equations of the utilization of the reactants are given in the (2) & (3).

$$U_{fH_2} = \frac{n^r_{H_2}}{n^{in}_{H_2}} = \frac{60000RTNi_{fc}}{zFP_{\text{fuel}}V_{lpm(\text{fuel})}x\%} \qquad (2)$$

$$U_{fO_2} = \frac{n^r_{O_2}}{n^{in}_{O_2}} = \frac{60000RTNi_{fc}}{2zFP_{\text{air}}V_{lpm(\text{air})}y\%} \qquad (3)$$

As such the pressure of the fuel and utilization are directly related and they can be given by the equations (4) & (5). From the mathematical equations it can be concluded that the amount of reactants consumed is directly proportional to the pressure with which they are fed.

$$P_{H_2} = \left(1 - U_{f_{H_2}}\right) x\% P_{\text{fuel}} \qquad (4)$$

$$P_{H_2O} = \left(w + 2y\% U_{f_{O_2}}\right) P_{\text{air}} \qquad (5)$$

From equation (6) it is clear that the pressure of reactants has a direct effect on the Nernst voltage which in turn determines the output voltage of the stack. Thus the pressure of the reactants has a direct relation with the voltage developed from the stack.

From the same (6) equation it could be seen that the operating temperature has an effect on the voltage generated and the current developed.

$$E_n = \begin{cases} 1.229 + (T-298)\dfrac{-44.43}{zF} + \dfrac{RT}{zF}\ln\left(P_{H_2}P_{O_2}^{1/2}\right) & \text{when } T \le 100^\circ C \\ 1.229 + (T-298)\dfrac{-44.43}{zF} + \dfrac{RT}{zF}\ln\left(\dfrac{P_{H_2}P_{O_2}^{1/2}}{P_{H_2O}}\right) & \text{when } T > 100^\circ C \end{cases} \qquad (6)$$

IV. Matlab / Simulink Model

With the available mathematical equations the matlab modelling is done for a 6KW 45 V PEM fuel cell stack. The model is shown in the fig. 2. The modelling is provided with a provision to vary the operating temperature, pressure of fuel and pressure of the air. The number of cells is taken as 65 and the nominal efficiency of the stack is taken to be 55 percentage. The composition of hydrogen is taken as 99.21 percentage while the oxygen is taken to be 21 percentage. The stack is connected with a RL load of 1.66 ohms. Air flow rate is fixed to be 300 lpm while the fuel flow rate is fixed to be 70 lpm. The efficiency of the stack is calculated as the ratio of the power output obtained to the reactants fed in to the fuel cell stack. Practically these PEMFC have an efficiency of 50 to 60 percentage thus 55 percentage is taken as the stacks efficiency in this model.

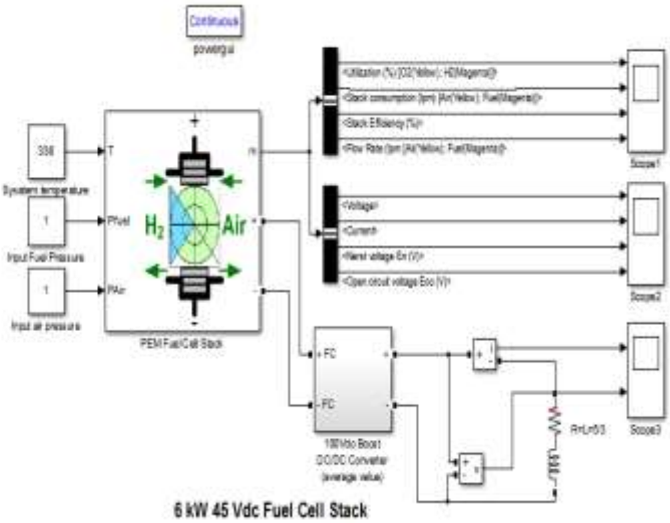

Fig. 2. Matlab/simulink model

V. Simulation Results

The simulations are done using the matlab model shown in fig. 2. Initially the simulation is done for an ideal pressure of 1 bar of pressure in both the fuel injection side and the oxidant injection side. The temperature is taken to be 338 K. With the above mentioned condition the nominal stack consumption for generating 45 Volts and 135 Amps is obtained to be 75.65

liters of fuel and 180 liters of oxidant. The simulated output obtained for the above mentioned condition is shown in the following figures. The Nernst voltage is obtained as 1.125 V. From the simulated output it is clear that the amount of fuel consumed and the amount of oxidant consumed is way too high for the power they are generating.

However from the equations (2), (3), (4), (5), (6) it can be understood that the amount of reactants consumed is proportional to the pressure with which they are fed.

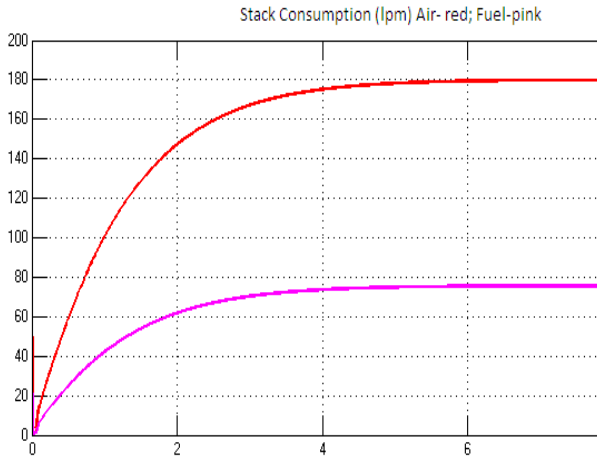

Fig. 3.Stack consumption

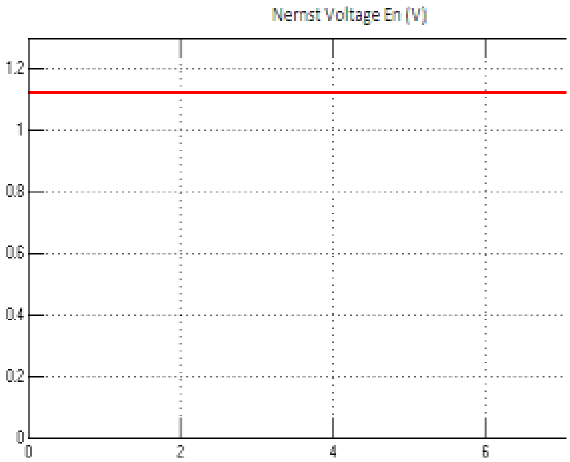

Fig. 4. Nernst Voltage

Thus by increasing the pressure of the reactants the quantity of reactants consumed can be varied. This is due to the fact that the serpentine pipes employed in the fuel cells will allow maximum contact between the membrane and the reactants with increase in pressure.

With the above mentioned points in mind the simulations are done with increase of pressure of fuels from 1 bar in steps of 0.25 bars till 2 bar. The simulated result obtained is plotted as a graph and is shown in fig. 7. From the graph it can be seen that by increasing the pressure of fuel from 1 bar to 2 bar keeping the pressure of oxidant and operating temperature to be constant the amount of fuel consumed gets reduced from 78 liters per minute to 38 liters per minute which is nearly 100 percent decrease in fuel consumed. The oxidant consumption, output current and voltage almost remains constant.

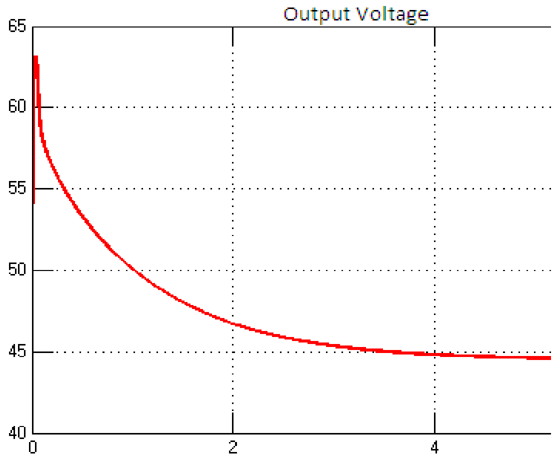

Fig. 5. Output Voltage

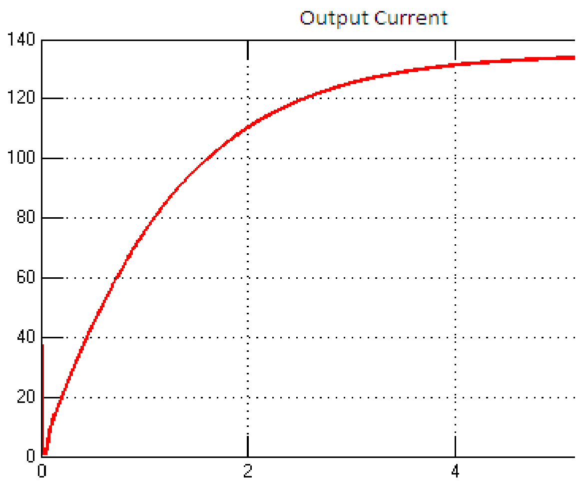

Fig. 6. Output Current

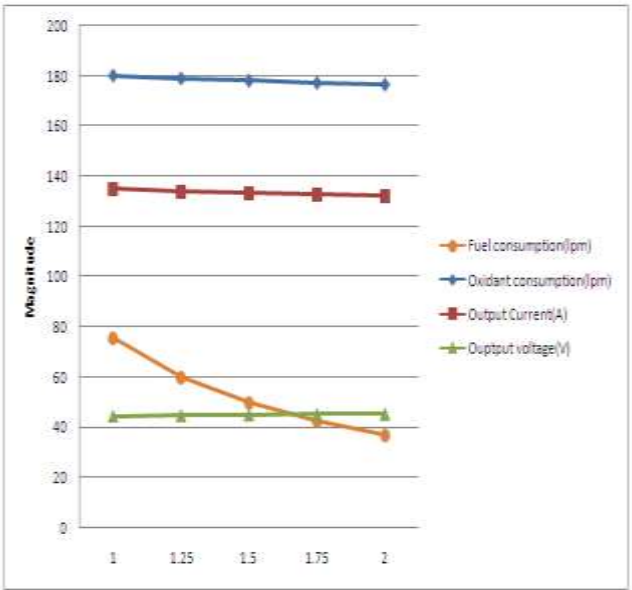

Fig. 6. With varying fuel pressure from 1 bar to 2 bar keeping oxidant pressure and operating temperatures constant

With varying oxidant pressure and constant fuel pressure and operating temperature the output obtained are plotted as a graph. The graph is shown in fig. 7. From the graph it can be understood that the amount of fuel consumed gets drastically reduced to 85 lpm from 180 lpm. It can also be seen that the output voltage and current almost remains constant. The fuel consumed doesn't get affected with the change in oxidant pressure.

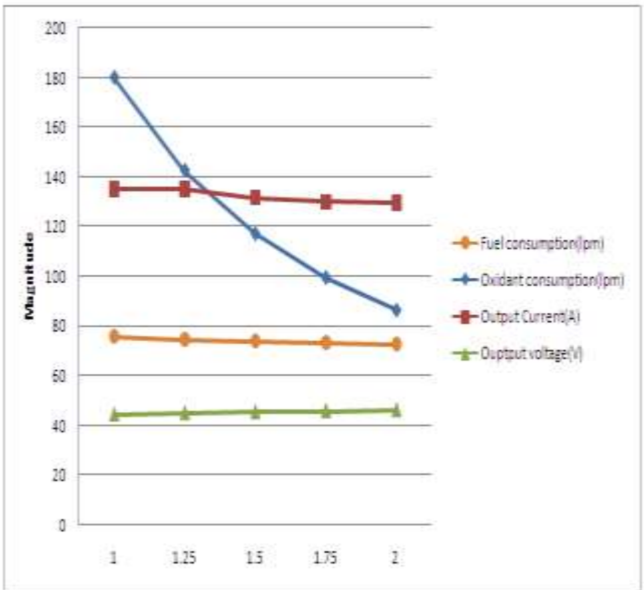

Fig. 7. With varying oxidant pressure from 1 bar to 2 bar keeping fuel pressure and operating temperatures constant

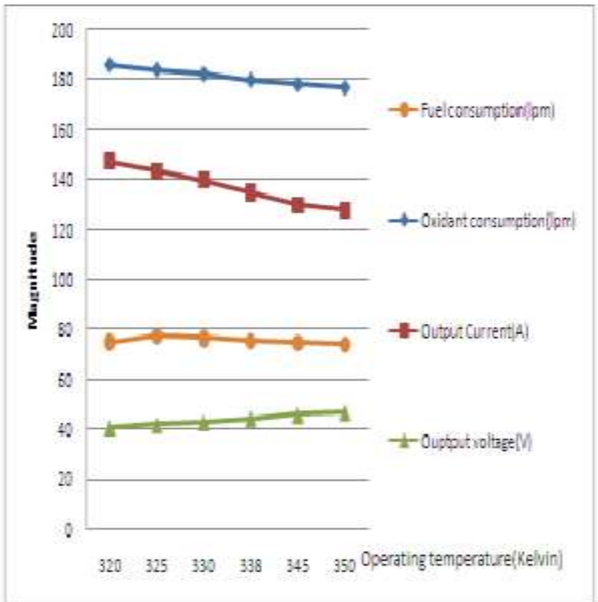

Fig. 8. With varying operating temperature from 320 K to 350 K keeping oxidant pressure and fuel pressure constant

The output obtained with varying operating temperature and constant fuel and oxidant pressure is shown in fig. 8. From the figure it can be seen that the oxidant and fuel consumed gets greatly reduced with increase in temperature. This can be backed by the equation (6). The flow of the reactants get actuated with increase in temperature and thus resulting in the reduced consumption. However the current delivered by the stack gets significantly affected with increase in temperature. This can be explained by the temperature effect. Thus for a nominal fuel cell stack to provide rated power it should be operating in the region which consumes less reactants and also providing rated power.

However the pressure of the fuel and oxidant cannot be increased beyond a certain point practically as the walls of the stack and the stack by itself has to be designed to withstand such a pressure. Additionally the potential that is involved in developing such a pressure should be accounted. The same applies to the temperature of the stack. After a certain point when the temperature of the stack is increased it results in the degradation of stack which will again reduce the life of the stack. Thus it leaves the designer with a narrow choice for choosing the pressure of the stack and the operating temperature of the stack.

VI. Inference from Simulated Output

The consumption of the fuel gets reduced by half when the pressure with which the fuel is fed is increased twice. The consumption of oxidant gets halved when the pressure with which the oxidant is fed is increased twice. The effect of these on the other parameters such as voltage and current are

minimal. When the operating temperature of the stack is increased the amount of fuel consumed and the oxidant consumed gets significantly reduced. However they also result in the degradation of the voltage and current of the stack

VII. CONCLUSION

The PEM fuel cell stack for 45V 6KW was statically analysed with changes in pressure of the reactants and the operating temperatures. It is backed with mathematical equations and is seen that the fuel consumed and oxidant consumed gets directly affected by the pressure of the reactants and operating temperature. With increase in pressure of the reactants and operating temperature the reactants consumed gets decreased. The obtained results shows a potential leverage that the fuel cell can get when the pressure of the reactants and operating temperature of the stack are properly designed.

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